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OPERATIONAL EFFICIENCY OF RUSSIAN STEEL COMPANIES: COMPARATIVE STUDY OF SFA AND DEA ASSESSMENTS

Master's Thesis by the 2nd year student
Concentration — General Track

Daniil Yakushev

Research advisor:

Yury V. Fedotov, Associate Professor

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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ
ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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АННОТАЦИЯ

Автор	Якушев Даниил Игоревич
Название магистерской диссертации	«Операционная эффективность деятельности российских сталелитейных компаний: сравнение оценок по моделям SFA и DEA»
Факультет	Высшая школа менеджмента
Направление подготовки	38.04.02 «Менеджмент»
Год	2021
Научный руководитель	Федотов Юрий Васильевич, доцент кафедры операционного менеджмента
Описание цели, задач и основных результатов	Цель: оценить эффективность российских сталелитейных компаний путем сравнения результатов их деятельности друг с другом и определить лучшие практики с помощью методов SFA и DEA. Задачи: 1. Проанализировать существующую литературу по эффективности, DEA и SFA. 2. Нахождение основных пробелов, которые есть в литературе по данной теме. 3. Выбор модель измерения и определите списка входных данных и выходных данных. 4. Сбор необходимые финансовых данных из отчетов компании. 5. Применение моделей DEA и SFA. 6. Сравнение результатов разных моделей. 7. Нахождение причин неэффективности компаний. 8. Предоставление выводов и улучшений по результатам полученных данных. Результаты: В этом исследовании мы разработали многоуровневый метод сравнительного анализа, основанный на подходах SFA и DEA. В данном исследовании анализируются российские металлургические компании с 2011 по 2020 годы с использованием моделей DEA (с подходом CCR - I) и модели SFA (с экспоненциальным подходом). Российские компании в последнее время теряют общую эффективность, основанную на нашей модели (с 93,5% в 2016 году до 85,8% в 2020 году). Средние сталелитейные компании более эффективны, чем крупные и малые сталелитейные компании. Сталелитейные компании, специализирующиеся на продуктах с высокой добавленной стоимостью, становятся более эффективными, чем компании, специализирующиеся на продуктах с низкой добавленной стоимостью. В завершение исследования были определены несколько компаний с лучшими показателями эффективности: НЛМК, Северсталь и Металлоинвест.
Ключевые слова	Эффективность, Металлургические компании, Анализ охвата данных, Анализ стохастических границ, Россия

ABSTRACT

Master Student's Name	Yakushev Daniil
Master Thesis Title	«Operational Efficiency of Russian Steel Companies: Comparative Study Of Sfa And Dea Assessments»
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Academic Advisor's Name	Yury V. Fedotov, Associate Professor
Description of the goal, task and main results	Goal: to evaluate the effectiveness of Russian steel companies by comparing their operating results with each other and identify the best performers using SFA and DEA methods Tasks: 1. Analyze existing literature on efficiency, DEA and SFA 2. Find the main gaps that this literature contains 3. Select the measurement model and identify the list of Inputs and Outputs 4. Collect the necessary financial data from company reports 5. Apply DEA and SFA models 6. Compare results of different models 7. Find the reasons for the ineffectiveness of companies 8. Providing conclusions and improvements based on the results of the data obtained Results: In this study we developed, a multilevel method of comparative analysis that based on SFA and DEA approaches. This study analyzes Russian steel companies from 2011 to 2020 using DEA models (with CCR - I approach) and SFA model (with exponential approach). Russian companies have recently been losing overall efficiency based on our model (from 93.5% in 2016 to 85.8% in 2020). Medium-sized steel companies are more efficient than large and small companies. Companies that specialize in high value-added products are beginning to be more efficient than companies that specialize in low value-added products. In finalizing, this study identified several best performer companies in terms of efficiency: NLMK, Severstal and Metalloinvest.
Keywords	Efficiency, Steel companies, DEA, SFA, Russia

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INTRODUCTION

The steel industry is one of the economy-forming industries in Russia. The products of this industry are used in construction, mechanical engineering, infrastructure, and household appliances. Russia has always been one of the key exporters of steel to the CIS market, and the main steel companies were vertical conglomerates that accompanied the production of steel from primary resources to the finished product.

Now the industry is especially in need of efficiency assessment for several reasons: industry 4.0 technologies are being introduced and the struggle for technological superiority in the steel market begins, prices for basic steel products are highly volatile, because of this, it is necessary to try to reduce production costs as much as possible in order to be able to withstand these shocks. It is for these reasons that steel firm managers and executives need to be efficient and make the most of resources to create economic value.

This work will concentrate on measuring technical performance, as this is the leading way to measure organizational performance. If steel production is not technically efficient, then it will lose revenue and profits, which must be invested in the digitalization of production and increased portfolio diversification. Other organizational performance metrics cannot account for the dynamics of change, and there are also difficulties in interpreting decisions to improve organizational performance. Therefore, this research will be relevant for steel companies.

The research gap which this paper tries to cover lies is that steel companies use metrics that yield quick results, but have many drawbacks, such as the difficulty of interpreting the results in a recommendation. DEA and SFA analyzes, on the other hand, can solve this problem and signal which resources should be reduced and reallocated more efficiently, that the output has remained at the same level. Many researchers have also used these methods to assess the performance of the steel industry in China, India and Vietnam, but this has never been done in the Russian market.

Theoretical contribution of this research is that we apply state-of-the-art analysis methods for multi-input and output data, using state-of-the-art analysis packages (DEA and SFA), and for the first time use these tools to analyze the effectiveness of the Russian steel industry together with the formation of practical recommendations for market participants.

The main aim of this paper is evaluating the effectiveness of Russian steel companies by comparing their operating results with each other and identify the best performers using SFA and DEA methods.

This paper aims to accomplish the following research objectives to reach the abovementioned goal:

1. What is the performance metric for a typical Russian steel company?
2. Who in the Russian steel market shows the best results in terms of the aforementioned efficiency?
3. Does the size of a steel company affect its performance?
4. Does the number of factories affect the efficiency of a steel company?
5. Does the type of product a steel company makes on efficiency?
6. What actions will allow Russian steel companies to improve their efficiency?

Summarizing, this work presents: a brief introduction to the steel industry, as well as the main trends that will affect this industry in the future. Thereafter, various definitions of effectiveness were reviewed to avoid ambiguity and the basics were defined. In addition, a detailed literary analysis of a short list of works devoted to the effectiveness of steel companies was carried out, the most popular models were identified, and a gap in Russian studies on this topic was discovered. data selection and time interval, including the specification of variables that will be selected as input and output data. The pros and cons of choosing quantitative analysis as the primary method have also been described. DEA and SFA were described and proven as the methods of analysis used, including the various pros and cons of one and the other method of analysis. The specifications of each of the models were also selected based on logic and previous experience from the literature. The data were analyzed in several ways of DEA and SFA, and the results were compared with each other, then subgroups were determined for answers to the main research questions. At the end, recommendations are given to businesses that will help move away from production inefficiencies.

This study uses quantitative empirical research. This method assumes a high-quality literature analysis and a clear formation of a research gap. Collecting data from major steel companies using Thomas Reuters databases. This study uses fixed assets, operating expenses and COGS as inputs and Net Sales and Net Profits as outputs. The efficiency will be gauged with the help of an add-in plugin for Excel, called DEA-Solver. Summing it all up, this study defines the criterion for finding the best performers on the steel market.

This research consists of several logical stages that add up to a single story. Starting with an overview of the steel market in Russia and the main trends, the definition of the concept of efficiency and a review of the literature with basic research on the efficiency of steel production. Then the main research method is determined, which consists of two modern methods of researching technical efficiency: Data Envelopment Analysis and Stochastic frontier approach. Then the specifications of these models are defined, as well as the main inputs and outputs of the model. Then a research is carried out, the main best performers are determined, and an assessment is carried out on the basis of the research questions. Finally, basic recommendations are revealed that can be useful for managers and owners of steel businesses.

1. MARKET REVIEW AND LITERATURE REVIEW

1.1. Overview of Russian steel production sector and main trends

The base of the steel industry began to form in the era of Tsarist Russia and received a big leap in development during the USSR. The main feature of steel production in Russia is the large distance between the production of different cycles. So, for example, a metallurgical plant can be located near an ore mine, but the coal required to provide heat for the steel process can be delivered from a completely remote place. To assess the effectiveness of this sector, we need to understand the history of this sector, which players are mainly present in the market, as well as which main types of products are produced and by whom are consumed.

Steel production in Russia has grown over the past 5 years and has grown on average by 13.8% per year, as can be seen from the figure 1. In 2020, against the background of the pandemic, steel production was reduced, because of this, the growth of metallurgical goods production slowed down. but remained positive from a monetary point of view. Nevertheless, according to Kommersant[1], in 2020, the largest companies in the Russian metallurgical industry reduced steel production by 2.4%, to 60.8 million tons. The positive growth in the volume of shipped goods of metallurgical production can only be explained by an increase in prices for steel products.

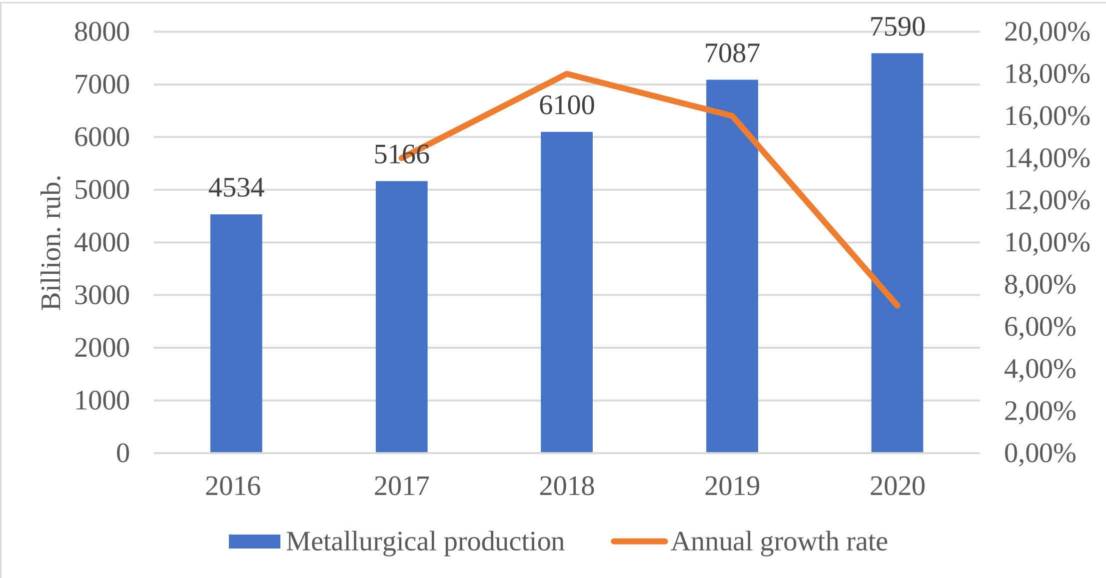

Figure 1 The volume of shipped metallurgical goods production in Russia and Annual growth rate, billion rubles

Source: Rosstat

[1] https://www.kommersant.ru/doc/4671379

This market in Russia can be called oligopoly, since there are 6 large players on the market, which occupy a large share in steel production. In total, NLMK, MMK, Severstal, Evraz, Metalloinvest and Mechel smelt 87% of all steel produced in Russia.

The main producers of flat products in Russia are NLMK, MMK and Severstal. They are located in the European part of Russia and produce steel, both by converting and using electric furnaces. The second method is more efficient because of the fewer resources required.

At the same time, the enterprises of EVRAZ, ChMK and Oskolsky EMK specialize in long products and steel billets, long products, and steel billets. These products are easier to execute and thus less marginal since there are fewer redistributions. Long products are a less consolidated grade of steel products, as new players are already entrenched in this market, and entry barriers are high due to the large number of required production capacities.

Due to the oligopoly effect, there are factors that can negatively affect the efficiency of this sector. Firstly, oligopolies are forced to engage in non-price competition, because of this, the costs of metallurgical enterprises increase, since they must maintain the current level of product quality and constantly improve their products. In the case of steel production, this leads to many investments in the development of a product portfolio and a decrease in costs, which are caused only by the race to reduce the cost of steel and an increase in revenues and profits due to the sale of high-margin positions. These include zinc rolled metal, stainless steel sheets and others. Furthermore, such competition provokes enterprises that were engaged in a construction project before the competitive collision to switch to flat products due to its stronger marginality compared to construction steel. For example, EVRAZ, one of the largest players in the construction steel segment, is going to diversify its portfolio towards high-margin products.[2]

Also, the high concentration of the market among several players provokes customers to buy metal only from them and, with no choice, these companies can use this situation and organize cartels, thus higher prices will be established for certain products, in contrast to the model of monopolistic competition, where prices would be corresponded to the market. This model of cartel conspiracy is confirmed in the steel markets, where large metallurgical plants of the vertical chain operate (Trüby, 2013).

But there may also be positive trends that are present in this market. Due to the high competition, oligopolists actively finance R&D, thereby developing new, improved methods of production, which can positively affect the efficiency of steel production. These new technologies

[2] https://www.metalinfo.ru/ru/news/104984

improve the vertical of steel production, for example, reduce the amount of required resources using cheaper production gases. But there may also be positive trends that are present in this market. Due to the high competition, oligopolists actively finance R&D, thereby developing new, improved methods of production, which can positively affect the efficiency of steel production. These new technologies improve the vertical of steel production, for example, reduce the amount of required resources using cheaper production gases. Also, players in this market develop their steel grades, which have higher capabilities than other grades, thereby spending less resources to achieve the same effect, for example, by developing strength. Thus, NLMK achieves an effect in revenue (due to the high-margin steel grade), spending less resources.[3]

It is also worth understanding how many percent of manufactured products are consumed by Russia. According to World Steel Association, the demand for steel is growing in Russia, but during a decline in business activity, this demand is decreasing, in the figure we can see that over the past 10 years there have been several falls, in 2015 and 2016 due to the skyrocketing of exchange rates, which led to an increase in the cost of production of many construction projects, as well as in 2020 due to a general decline in business activity amid the Coronavirus pandemic.

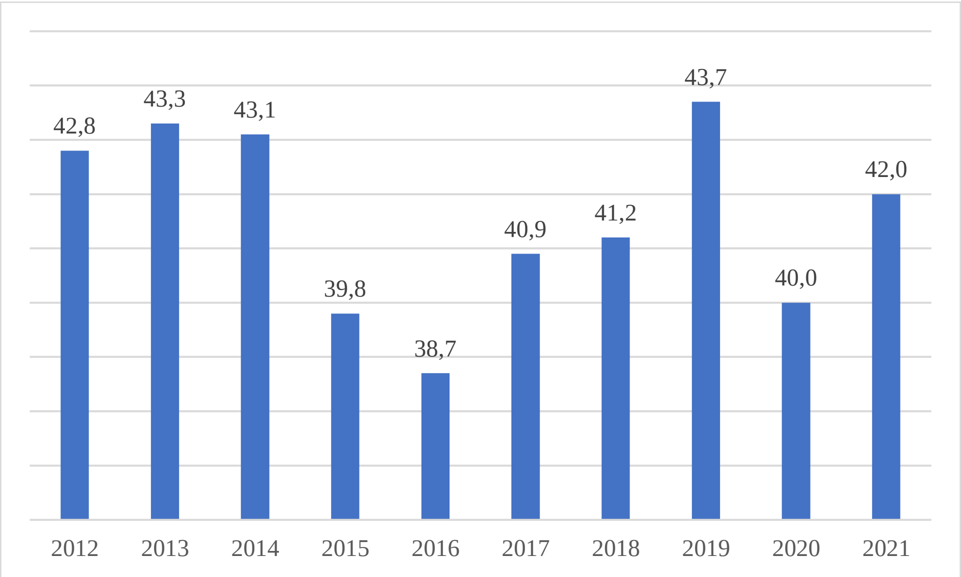

Figure 2 Consumption of ferrous metallurgy products in Russia, million tons

Source: World Steel Association

The main demand for metal products of Russian enterprises is presented by the construction industry, fittings, beams and other building materials. The second industry is the processing industry (shipbuilding, production of cars, household appliances, etc.) It is interesting

[3] https://www.metalinfo.ru/ru/news/121181

that approximately the same distribution is observed in China, the largest consumer and producer of steel.

As it is clear from the previous topics, Russia produces more steel than it consumes, so a large part of the produced metal products is exported. The main Russian exporters of flat products are Belarus, Turkey, and Uzbekistan. While the main pipe exporters are also the countries of the CIS and Europe. Despite this, the export of high-margin positions does not occupy a high share (33%) in the export structure of Russian Steel, as can be seen from the figure 3.

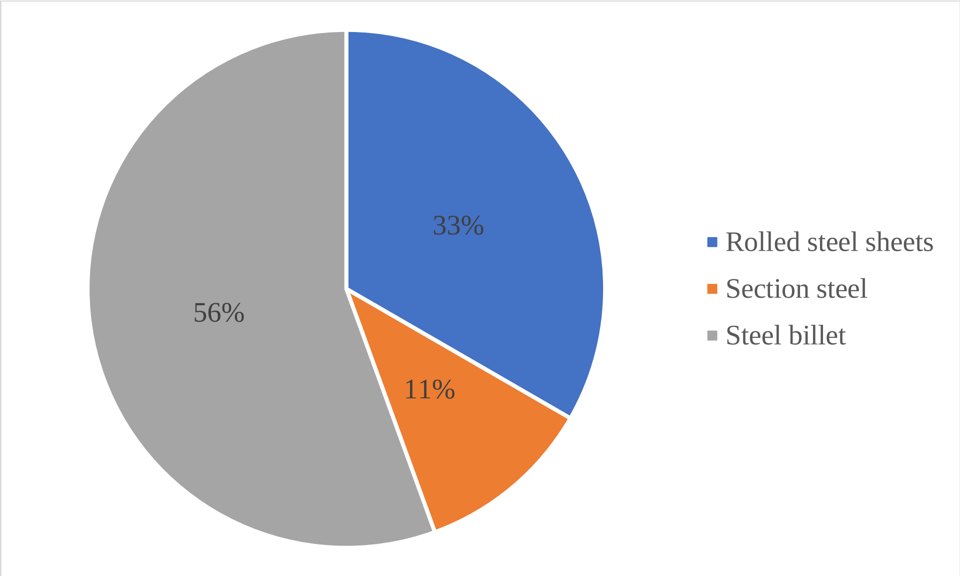

Figure 3 Structure of export of steel products in Russia in 2017

Source: Metal Expert

Moreover, the main share is accounted for by the export of steel billets. This is due to the presence of our own steel-rolling facilities abroad and the low cost of billets in Russia, caused by a large resource base and the devaluation of the ruble. In the future, against the background of the development of the product portfolio of the main players in this market, a shift and decrease in this share in the export of steel products can be expected.

It is important to understand that prices for steel products are formed by the market and largely depend on the balance of supply and demand in it. Also, steel prices are largely influenced by the prices of primary raw materials: iron ore, coal, and scrap metal, as an alternative to iron ore for electric furnaces. Also, the level of prices for various metal products differs and largely depends on the quantities of the processing stage of a particular type of product, thus products with many processing stages have a higher price. Due to the emergence of a larger share of added value in the structure of the price of metal products, such types are less prone to volatility, thus they can take steps to achieve production goals in terms of rescue. More sustainable pricing with higher margin products allows steel companies to plan more precisely how much cash they need and operate more efficiently (Garanina, Petrova, 2015).

In the steel market, the production of high-margin products can be afforded by those companies that have the required number of production facilities. Electric furnaces are becoming such essential machinery, since they allow the production of steel with more accurate indicators, as well as sheet metal machines, due to the different periods of capital investments in the basic capacity, not all companies can afford it (Lee, Ki, 2017).

The main trends in the ferrous metallurgy sector in Russia can be divided into several parts. Product innovation, business model innovation, and process innovation.

Product innovation is real need in the steel industry as more and more demands are placed on the metals produced by the factories. One of the directions of development for companies is to increase the exploitation properties of metals, such as increased metal strength or increased ductility. Often, enterprises require large R&D budgets to develop such areas. In this regard, Russia lags foreign competitors, since historically most of the R&D was carried out by state institutions, institutions, and not by the enterprises themselves. In terms of expenses from revenue, R&D expenses are not comparable to competitors, in Russia they amount to about 0.1% of revenue, while foreign competitors account for about 1.5% -2% of revenue.

The release of high-tech products also requires high capacities, a certain critical mass of capital and the necessary technological resources that are available only to foreign companies. In Russia, companies are also behind competitors due to insufficient market capacity within the country for the development of technological breakdowns.

One of the solutions in this area could be the development of a customer base and the creation of joint institutions with the main steel consumers in Russia. In the short term, it is also possible to build up an export customer base that consumes complex products.

In the future, companies expect a massive shift to high value-added products and the creation of large customer engineering units that will develop complex projects that will require a large supply of innovative metals. Whereas metallurgical companies will target metals demand and create specialty metals at short notice as requested by customers. The implementation of such projects and the creation of metals with new properties will require large capital, the implementation of which will require not only the latest equipment that can achieve the necessary properties, but also equipment that will meet new environmental standards that will allow Russian companies to orientate themselves to foreign markets (Zhang, Y. -., Shi, W., & Jiang, L. 2020).

The main events that shape process trends include the high requirement for the base product and the pressure from the price side to this product, the introduction of Industry 4.0, the emergence of new metallurgy technologies, for example, new summer complexes that combine the melting and rolling stages of steel production. All this requires new technological solutions and costs.

Constant pressure on the cost of the base product has led major steel companies to adopt Lean and Continuous Improvement technology. These approaches to the formation of business processes make it possible to gradually reduce the costs of producing basic products, thereby providing companies that are the first to introduce this type of technology - a competitive advantage. One example of the introduction of this type of technology can be the example of Severstal and their implementation of business systems in the main production process, these incomes allow Severstal to form a long-term competitive property through productive labor activity, customer focus and the formation of a corporate culture.[4]

Those companies that did not introduce such innovations have already turned out to be less competitive due to the unstable prices for steel products. To solve these problems, the company will need to expand the current technology enterprises, expand the infrastructure and create institutions that promote the formation and implementation of mechanisms to ensure lean production.

One of the motivational steps towards the formation of process innovations is also attributed to the requirements of the community to reduce CO2, since companies in this industry produce about 1/3 of CO2 emissions (Karakaya, E., Nuur, C., & Assbring, L. 2018). Therefore, the formation of a culture in which the introduction of a gradual improvement in production will take place will be a step that will ensure a smooth transition to lower emissions without high losses in profit.

One of the next steps to improve business processes can be the introduction of Industry 4.0 technologies. These include IoT technologies, which serve as sensors to help collect the necessary data and from this data to create models and optimize production in real time (Xu, L. D., Xu, E. L., & Li, L. 2018). For the metallurgical industry, technologies from this list can improve production in many stages. the introduction of sensors, which will allow monitoring the temperature, will be compared with data on the quality of the metal and its properties. Models will

[4] https://chermk.severstal.com/about/business-system/

be formed that will, on the basis of big data, form an opinion about the required temperature regimes specifically for the required product. All this will allow the company to reduce the costs of manufactured goods.

All of this requires large investments in infrastructure (sensors, instruments, computers, and servers). As well as IT and big data competencies for creating and working on arrays. Such colossal costs should pay off in the long term, since these technologies will provide an increase in the productivity of steel companies (Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. 2018).

The next step in shaping future technology trends can be the creation of new business models. Many players are trying to do downstream value chain integration, which allows them to design more precise steel products such as pipes, sheets, metal structures and profiles. This approach allows producers to increase the cost of their product per ton of metal. But this approach requires large investments in the development of joint ventures to create a product in conjunction with R&D institutes. A thorough examination of the consumer's needs should also be accompanied by an examination of their specific needs.

Voestalpine, a company that produces bodywork parts for cars, turbine propellers and aircraft components, they say that their innovations are inextricably linked with the consumer, and that their client is no longer waiting for the product that the company provides, but what problem he can solve, so the company is more realizing not products, but projects together with a product that solve the client's pains, and what is important, bring more revenue.[5]

The main trend in creating new business models lies in creating additional opportunities for the client and creating additional value for them. Together with Industry 4.0 technologies, such opportunities become available to companies in the metallurgical industry (Müller, J. M., Buliga, O., & Voigt, K. -. 2018).

An increase in consumer interest in green products can also serve as a lead to changing business processes. Now, when creating new infrastructural objects, they pay attention to the fact that it must have environmental standards and therefore the responsibility also passes to the suppliers of construction materials (El-Kassar, A. -., & Singh, S. K. 2019). In our case to the metallurgical companies.

An additional source of revenue for companies can also be the offer of design and engineering services for facilities. To do this, the companies will need to create additional

[5] https://www.voestalpine.com/welding/ru/Kompaniya/Znaniya/Issledovaniya-i-innovacii

subdivisions that, at the client level, will be responsible for communicating with the client and handling client data with the subsequent creation of projects.

Also, in the context of the current situation of monolithic production, mini factories can be created, which will provide metal to a small local part of the market.

In the next part, we will talk about the application of management theory and the formation of the concept of efficiency in this work.

1.2. Defining efficiency concept and applying management theories

One of the goals of this work is to analyze the assessment of the effectiveness of Russian steel companies. To achieve this goal and avoid the problem of ambiguity, we must clearly define the concepts in which the research will be carried out. In this part, we will cover the fundamentals of efficiency that will be used in the following chapters of this work.

Nowadays, term efficiency is widely used in industries that include the processing of resources and the production of similar materials, to which the metallurgical industry is also slightly related. This gives us the chance to fully operate in existing terms, which will make our work more understandable and structured. For a clearer explanation of the term efficiency, we also consider the most similar words that are often confused with the term efficiency. Words like effectiveness and efficacy.

Effectiveness relates to getting the right things done. Peter Drucker in his works, he said that for the success of enterprises it is a necessary condition for success in business (Peter F. Drucker 2006). In other words, it can be said that the goals that were set by the business and the degree of their implementation can be considered effectiveness. If the percentage of goals achieved is high, then in this vein the company is successful in terms of the term effectiveness.

Efficacy is the ability to perform a task to a satisfactory or expected degree. This term is mainly used in pharmacology, medicine, and theology. It accurately refers to the manufactured product in medicine and pharmacology and assesses the degree of the drug's effect on a person from the declared properties.

There are many concepts of efficiency in the literature, but there is one that is defined in the model and can be applied to any type of efficiency. The efficiency of any DMU is obtained as the maximum of the ratio of the weighted outputs to the weighted inputs, provided that the analogous ratios for each DMU are less than or equal to one (A. Charnes, W. W. Cooper and E. Rhodes, 1978).

It is also worth separating two approaches to determining the efficiency according to this definition, which depend on the setting of the optimization variable (Cooper, W. W., Park, K. S., & Pastor, J. T. 1999):

- Input oriented approach - minimize inputs or in other words, the efficient use of resources, a method in which, with a decrease in inputs, the outputs remain unchanged
- Output oriented approach - outputs maximization where inputs remain unchanged

Input oriented approach is a more popular method, since resource minimization is a more feasible and reliable way to increase efficiency, since companies often implement projects to reduce costs, and firms can also have huge resources and have high profits, but still use them ineffectively. Output oriented approach is a more difficult method to implement, since with current resources it is more difficult to increase output without any change in technology and it is not always obvious how to achieve the model's indicators.

Farrell made a distinction between the above efficiency, which he named "technical efficiency", and other types of efficiency, which he named "cost efficiency" and "overall efficiency” (Farrell, M. 1957).

Overall efficiency is when all goods and factors of production in the economy are allocated or distributed in the most valuable directions, and waste is eliminated or minimized. From the point of view of the firm when it uses the maximum of its capabilities and resources and creates the maximum achievable output. Technical efficiency and allocative efficiency add up to overall efficiency. In order for an enterprise or an economic agent to be an overall effective, it must be both technically and allocatively efficient at the moment of time (M. J. Farrel, M. Fieldhouse 1962).

First mentioned technical efficiency in Schickele R. (1941) works. Technical efficiency is the efficiency with which a given set of resources is used to produce a result. A firm is considered technically efficient if it produces the maximum output with the fixed amount of resources such as labor, capital, and technology. (Input-oriented approach) Or if it produces the fixed output with the minimum amount of resources such as labor, capital, and technology. (Output-oriented approach)

The next step towards efficiency is allocative efficiency. Even though technical efficiency allows you to optimize the amount of resources that are used in production, different resources cost differently, therefore the optimization model includes resource prices. Allocative efficiency allows both to consider these prices and to optimize the resources used, considering their cost.

Basically, you can combine all the performance definitions into a single table 1.

Table 1. Types of efficiency

Types of efficiency	Description
Overall efficiency	All goods and factors of production in the economy are allocated or distributed in the most valuable directions, and waste is eliminated or minimized.
Technical efficiency	A firm is considered technically efficient if it produces the maximum output with the fixed amount of resources such as labor, capital, and technology. (Input-oriented approach) Or if it produces the fixed output with the minimum amount of resources such as labor, capital, and technology. (Output-oriented approach)
Allocative efficiency	The efficiency at which the optimal amount of resources or output is optimized considering the prices of resources.
Productive efficiency	Efficiency in which an economy or an economic entity, within the constraints on a production function, is not able to increase the output of one product without decreasing the quantity of another. For example, when choosing to produce two goods (boots or shirts), with limited resources, you cannot increase the current volume of boots production without reducing the number of shirts produced, since new boots will require machines that produce shirts. It is also comparable this efficiency with Pareto efficiency. (Hosios, A. J. 1990).
Efficiency of scale	Efficiency, which is associated with the fact that with an increase in production, there is a decrease in the amount of resources required for the production of a unit of production. That is, the more a firm produces, with a positive return on scale, the cheaper it is for the firm to produce a unit of output. (McAllister, P. H., & McManus, D. 1993).

Source: author

This section explains the basic concepts of efficiency that are used in the literature, it is important for us to understand when calculating efficiency to understand in what way we are considering it.

1.3. Analysis of existing efficiency studies in steel industry including SFA and DEA

There is now a lot of research on the development of efficiency in steel production, as the steel industry develops and requires great changes, both in terms of environmental standards and in terms of efficiency. A summary of all the methods that will be listed in this section can be found in Appendix 1. This appendix also contains a map of the approach and variables that the authors used as inputs and outputs.

Basically, researchers use the DEA (first introduced by Charnes, Cooper and Rhodes (1978)) and SFA methods to analyze the performance of companies, there are also other approaches, for example, regression analysis, but still, these are often the above models with minor improvements.

Interestingly, the main research is carried out in the country that is the main producer and consumer of steel - China. On the example of China, most of the studies related to the efficiency of steel companies for different years of the existence of steel companies in China and with different hypotheses are based. There are also studies based on the markets of India, Vietnam, and Mexico.

After analyzing the main literature on the effectiveness of steel production, it becomes obvious that in Russia this is a research gap that this work is trying to solve.

1.3.1. Investigation of operational efficiency of steel companies around the world

This part will present studies examining the effectiveness of steel companies in chronological order. Also, this literary review will show by what methods scientists are suitable in assessing the effectiveness of steel companies. In this section, you will see that researchers have different approaches to measuring effectiveness.

(Ma et al., 2002) calculated technical efficiency and Malmquists productivity metrics via DEA and MALM for a sample of 88 enterprises that produce 72 percent of the industry's output were determined over the period 1989-1997 to achieve some insights on recent China economic reform. As a result of the DEA assessment, Chinese steel companies achieved an efficiency rate of only 63%, suggesting that there was enormous room for improvement. Small and medium-sized enterprises had a negative impact on the rating, while large enterprises showed good ratings. Also, enterprises that produced steel and high-margin products were more efficient in relation to enterprises that produced base products or cast iron. Also using the model MALM after after the DEA model usage, showed that the problems of Chinese steel enterprises are not only in technical efficiency, but also in the acquisition of resources that are not efficient in terms of price. This study is useful as it provides an example of using the DEA model to calculate technical efficiency, and provides a classification into small and large enterprises, which we can use in the example of Russia.

(Li et al., 2019) examined data envelopment analysis (DEA) model and a global Malmquist-Luenberger index model based on data of China's iron and steel enterprises (ISEs) from 2005 to 2014. In their work, they assessed environmental governance efficiency, which, according to their findings, remained at a low level over the past 10 years after environmental regulation on the EGE of China's ISEs. The bootstrap DEA method was also used, which allowed us to take into account the bias and adjust the result in the work, as a result, an effective estimate was obtained that fell into the confidence interval and which adjusted the final value. This work is interesting because it is done relatively recently and evaluates the indicators that are nominated. Also in this work, further work has been carried out on the DEA model, which improves the assessment of indicators.

(Filippini et al., 2020) provide total factor productivity (TFP) on firms in China's steel industry by using Törnqvist index and Data Envelopment Analysis on data of China's steel companies for the years 2003 to 2008. In their work, they calculated not only found facts proving an increase in the technical efficiency of steel companies, but also based on these figures calculated the overall cumulative effect of the Chinese government's support for steel companies, as well as the effects of increased technical efficiency. By finalizing all the work, the researchers were able to prove the effectiveness of the energy programs that the government of China is carrying out. This work will be of interest to us, since in this work many factors were selected for the model, including gross output, employees, total assets, current assets, intermediate inputs, age, total costs, and capital price.

(Nguyen & Tran, 2021) approached the problem of efficiency from the other side by using regression construction to determine which factors influence the efficiency indicator the most. They chose ROA as an indicator of efficiency. The model was built on data from 26 Vietnamese steel companies from 2012 to 2019. The indicator of profit after tax and the indicator of return on assets was taken as an indicator of efficiency. The result of this study was the established link between business efficiency and the increase in the company's assets, and it was also proved to link between business efficiency and the amount of debts of the company (receivables) in the opposite direction. The practical recommendation was to increase these indicators if the firm wants to be technically efficient. It will be useful for us to draw conclusions about the company's assets, since we now understand that they need to be included in the model for assessing performance.

1.3.2. Global SFA Research on the Effectiveness of Steel Companies

(Movshuk, O., 2004) used the method stochastic frontier model of Battese and Coelli (1995) with a translog specification and Cobb-Douglas specification for analyzing technical efficiency for China's iron and steel industry of SOE reforms over a long time. By his analysis, he found that the size of Chinese steel companies does not greatly affect technical efficiency, and also that Chinese steel companies have increased the amount of metal produced and increased production frontier, but their technical efficiency has not improved much, which indicates the fact that the Chinese companies have a stimulus for improving the situation. The paper is interesting because it uses 2 specifications and compares them to each other. Also, the author found an interesting feature that large metallurgical companies did not have any superiority over small ones in terms of technical efficiency. It will also be useful for us to use the author's findings, since he built his model on the data of the main Chinese players, which occupy 85.5% of the Chinese steel market.

(Kim et al., 2006) investigate iron and steel companies of over the world on technical efficiency by using a non-stationary stochastic frontier model for the period of 1978–1997. Initially, the authors had a hypothesis that could affect the technical efficiency of steel companies, this is privatization, economies of scale and equipment development. In their work, the researchers found that privatization greatly increases the efficiency of metal enterprises, while other factors had less impact. Among other things, results were obtained that indicate that the more investments steel companies received in relation to their revenues, the more efficient they became due to more high-tech equipment, therefore, for more efficient operation of steel enterprises, they need more capital investments. This work is interesting to you, since it uses an exponential model that can be applied in other studies, and also provides practical conclusions on optimizing technical efficiency, which consist in the maximum privatization of the steel industry by individuals.

(Wanghui, L., & Bing, H., 2009) built a stochastic frontier by using Cobb-Douglas approach data decomposition into capital and labor based on data from Chinese steel companies from 1981 to 2003. The result of this effort is the information that improved technical efficiency can have a profound effect on improving the steel industry in China. The researchers used The Kumbhakar's method, which allowed them to build a stochastic frontier, as well as determine a way to calculate overall productivity change. The main model took into account factors of production like capital and labor and used logarithmic values to make the Cobb-Douglas function. As a result, we got the values and frontier in the time interval, the authors saw the trends in time based on graphs. This work will be useful to us, since here the SFA is applied in time and using the Cobb-Douglas function, this work will also confirm the correctness of the approach in terms of improving technical efficiency.

(Wang & Feng, 2011) analyses scale efficiency of China ‘s iron and steel industry based on data from 1999 to 2009 using both methods Data Envelopment Analysis and Stochastic frontier approach. In their work, they used not so much input and output data, only 2 input (average balance of fixed assets and annual average of staff number) and 1 output (annual industrial value). Through analysis, they showed that there is a huge difference between the technical efficiency of public and private steel firms. One of the recommended improvements for state-owned steel firms, which the authors propose to increase the scale efficiency. The main limitations are the small selection of inputs and outputs for the model. This work is of interest to us, since when analyzing this problem, the authors used two methods at once and compared different results, which showed the same result (Data Envelopment Analysis and Stochastic frontier approach.

1.3.3. Global DEA Research on the Effectiveness of Steel Companies

(Yayar et al., 2012) build a DEA model with 2 approaches (input-oriented Chames, Cooper, Rhodes (CCR) Model with constant returns to scale and input-oriented Banker, Charnes,Cooper (BCC) Model with variable return to scale) based on data companies of Iron-steel Basic Metal Industry for 2010 and 2015, using financial indicators to calculate efficiency. In this paper, 2 concepts were considered, both technical efficiency and allocative efficiency. In two models, the best performance was calculated in terms of both efficiencies. As a result, 3 companies were singled out as best performers by the CCR method, as well as 9 companies by best performers by the BCC method. Summarizing all the work, the authors provide recommendations for more economical use of resources in the future for these companies. This study is interesting to us, since both financial and economic indicators (the number of employees in the company) were taken to calculate the efficiency, we also made a temporary difference in the change in technical efficiency for 2005 and 2010 and considered the technological progress of these firms. But despite this, this study has a limitation associated with the choice of only two years for the analysis, that the author needs to take a longer period of time to get around this limitation.

(Mitra Debnath & Sebastian, 2014) In their work they calculated the relative efficiency of the steel manufacturing units by output-oriented approach in data envelopment analysis (DEA). The main purpose of their work is to calculate scale efficiency (SE) and technical efficiency (TE) of main steel manufacturing companies of India. They use as input variables: gross fixed assets, total energy cost, total number of employees and currents assets. They use as output variables: income, sales, PBIT and PAT. Collecting this data from 22 major steel companies in India, they conducted this survey for 2007 and 2008. After the analysis, the best performers were derived, which are the following companies: AML Steel Ltd and VBC Ferro Alloys Ltd. This study is interesting to us, since financial indicators were used in this work, since steel companies have heterogeneous products, which, even though the same amount of metal is used, may cost differently due to a different number of production iterations. Also, this work breaks down companies into classifications by territory and draws conclusions based on the territorial availability of materials, as the basis for success in the technical efficiency of production. The main limitation of this work is the small number of years the study covers, which makes it difficult to track the progress of steel firms in India.

(Yang et al., 2017) assessed the efficiency Chinese steel and iron industry from 1996 to 2010 by using DEA approach and smoothed bootstrap network DEA strategy to examine sensitivity of calculated efficiency measure. Also in this work, the frontier was calculated, which should be achieved in an ideal situation by companies from this industry. In this work, the author also focused on the geographic development of regions in terms of technical efficiency. The result of this study was information that the eastern part of China is more developed than the western part. In addition, the researchers found that technical efficiency had improved dramatically over the five years, influenced by the Eleventh Five-Year Plan. This study is useful for us, as it provides a new approach using an improved DEA method, which allows us to conduct a sensitive analysis, as well as to adjust the distance between the expected frontier and the steel company. It is also another confirmation that the geographical location of companies in a country can affect the technical efficiency of this company. Conclusions are also useful, as this paper presents methods that can improve the situation.

(Feng et al., 2018) analyzed energy efficiency of iron and steel industry (ISI) based on data from 2000 to 2014. Like the previous work, this work tried to assess the environmental performance of the sector, but what is remarkable, in this work, territorial efficiency was considered, that is, the various provinces of China were assessed. Unlike previous work, in this work, with the help of DEA analysis, scientists found that China made a big leap forward in terms of environmental efficiency. This work is interesting to us, first of all, because in this work not only the fact of the growth in the technical efficiency of steel companies is analyzed, but also various factors that could have influenced this (technological progress) are given. Differences between regions are also given, namely the difference in their technological development and differences in scale efficiency, which influenced the development of some provinces.

(Nguyen & Nguyen, 2020) in their work, we used DEA analysis with the addition in the form of gray system theory to analyze the effectiveness of the Vietnam steel industry on the period of 2011–2019. For the de-model, they used three indicators for the input data (Fixed assets, Cost of goods sold Capital, Operating Costs) and two indicators for the output (Net sales and Net profit). In their work, they calculated the indicators and found the best performers for several years in this sample, and then repeated the same calculations, but considering the proposed unions. The result has been an improvement in technical efficiency in the aggregate of previous results through pooling of resources and economies of scale. So in the work of the top performer before the merger, the performance indicator was soon equal to 2.39, and after the merger, the performance indicator was soon increased to 4.05, which may become one of the incentives for the merger of firms. This work will be useful for consideration because of the good approach to the construction of the DEA model and the choice of variables, as well as the further application of this model to analyze effective future events. This work is an excellent example of how the DEA model can provide analytical guidance to firms.

Conclusion

In order to understand the current situation more accurately in the steel market, the steel market, the main players and the market dynamics were described in a cartographic manner. They also touched upon the main technological trends that will influence this industry in the future. Thereafter, various definitions of effectiveness were reviewed to avoid ambiguity and the basics were defined. In addition, a detailed literary analysis of a short list of works devoted to the effectiveness of steel companies was carried out, the most popular models were identified, and a gap in Russian studies on this topic was discovered.

In the next chapter, the methodological part of the work will be explained, the model, as well as the necessary data and the necessary interval for carrying out the research, will be characterized.

2. METODOLOGY OF THE RESEARCH

This study is presented as a quantitative study, which consists in finding effective and ineffective steel companies in Russia. The main purpose of the work is to calculate performance estimates using advanced analysis methods. The following parts of this chapter will expand on the data and the preferred model and specifications of that model in more detail.

2.1. Specification of data and sample for analysis

To conduct this study, the annual financial data of the largest steel companies in Russia were collected. The data was taken from the Thomas Reuters database, a trusted source of company financial information. Previous research experience has shown that an interval of 10 years is sufficient for this type of research. For DEA analysis, we need to be especially specific, since the results of this method cannot be genialized, which is why we take for our analysis accurate data from companies that occupy 87% of the Russian steel company market.

The period of 10 years was not chosen by chance since this is a sufficient period to see the rise or fall of the technical efficiency. Over the past 10 years, steel companies have already begun their path to Industry 4.0 and production optimization, so at this time it is possible to track the dynamics of technological efficiency.

Also, these data will allow us to assess the feasibility of technical efficiency by several factors: the company's order, its geographic location or direction of production (sheet steel and pipes or bar steel).

The choice of specific data is a complex process for the formation of the final model and remains at the discretion of the author of the model (Kolosova, 2011). For this study, 6 Russian steel companies were selected, which greatly limits our capabilities in terms of modeling, but due to the fact that only Russian companies will be present in the sample, this will increase the reality of practical recommendations, since we will be comparing Russian companies that were in one environment and in the same economic conditions (duties, taxation, etc.).

One of the ways to measure the operating efficiency of steel companies is to compare their financial results, for example, in the case of revenues, we will compare the monetary indicator, since the products of steel companies are heterogeneous and it would be wrong to compare companies in the production of metal products, since one of the companies may produce products with low value added with relatively low costs, but this company will have more volume at lower costs. Therefore, the input data and output data will be based on the financial data of the steel companies.

The first input is Fixed Assets which includes the cost of equipment, buildings, and other tangible assets. This will allow us to understand with what production capacities the companies are approaching steel production and will allow us to determine the assets that may not be required to generate the required amount of revenue. This indicator is characterized as input data, as steel enterprises use fixed assets for the production of the main product - steel. This input was also used in the work: Movshuk, O. (2004), Wang & Feng (2011), Yayar et al. (2012), Mitra Debnath & Sebastian (2014), Yang et al. (2017), Nguyen & Nguyen (2020).

Another input is Operating Costs the costs of companies that are directly related to the release of products, which directly include the costs of creating metal, but also the costs of managing and selling the goods. This parameter should be considered, since we will compare companies geographically and those companies that are too far from buyers will incur additional costs for selling products. Also, many companies are implementing projects to improve sales, which can also affect this indicator and make the company more effective. This input was also used in the work: Nguyen & Nguyen (2020).

The last input we will be using is COGS. which directly includes all resources associated with the sale of steel products. Here I would like to look at the costs only directly affecting the production of products, in order to see how much the company differs in technological terms, again here it is worth considering that for enterprises with high added value these costs will be higher, but the expected revenue will also be higher. This parameter is considered as input, as it is a direct cost that the company invests in producing steel. This input was also used in the work: Kim et al. (2006), Nguyen & Nguyen (2020).

The first output is Net Sales, which includes all the revenue that steel companies receive. This indicator is considered as an output data, since the main way of obtaining revenue from steel companies is the sale of steel, it also allows us to consider the fact that steel companies have differentiated products, so companies with high added value products will not stand out as ineffective in the case of the choice of input data as the volume of steel products produced. This output was also used in the work: Movshuk, O. (2004), Yayar et al. (2012), Mitra Debnath & Sebastian (2014), Filippini et al. (2020), Nguyen & Nguyen (2020).

The second and final output is net profit, which considers the profitability of steel companies and considers those who make positive profits to be successful. It is important to consider this indicator, since not always companies with large revenues can be profitable, since the market for steel products is very volatile. This output was also used in the work: Yayar et al. (2012), Mitra Debnath & Sebastian (2014), Nguyen & Nguyen (2020), Nguyen & Tran (2021).

With this indicator, there are some restrictions on our model, so the profit cannot be negative for the model. There is a simple solution for this problem, which is to normalize the variables, thus the profit will be in values from 0 to 1 and not include negative values, while the model will use natural or normalized values without difference.

2.2. Selection of research methods and specification

The main goal of this work is to assess the efficiency of steel enterprises in Russia. therefore, the bulk of this work will be focused on quantitative analysis, since it will allow us to process data, build statistical models, linear software packages (DEA) and parametric approaches (SFA), so the choice of a quantitative analysis method looks reasonable.

Also, quantitative analysis has positive qualities, such as effective in terms of cost of its implementation, as well as the speed of data collection and their objectivity. With the help of quantitative analysis, we can make sure that our data does not contain the personal interests of company leaders and we can objectively draw conclusions based on this data. Including with the help of systematized data, you can carry out many tests of hypotheses.

This approach provides us with speed and objectivity, but it also has various disadvantages that are not present in qualitative analysis. First, the cheapness of data is ensured by the fact that it is secondary data, so it is very important to choose reliable sources that monitor the correctness of the data in the databases. That is why the Thomas Reuters database was chosen as a reliable database. Also, this data was checked from primary sources (financial statements of companies). Secondly, it may be difficult to interpret the findings, while in a qualitative analysis we can more accurately forge requests and answer questions. We will correct this lack of quantitative analysis with the help of understandable hypotheses in which a situation of misunderstanding of data cannot arise.

The quantitative part of this work will include analysis of efficient and ineffective steel companies, which will be identified using modern approaches to analysis using DEA and SFA methods. The data will be presented in the form of tables and graphs with conclusions.

Research involves the use of two methods of analysis: using a parametric approach (SFA) and using a non-parametric approach (DEA). In both cases, we have to use input and output, but in the case of SFA, we also have to specialize the production function with a certain type of distribution (gamma distribution, truncated normal distribution, half normal distribution, and exponential distribution). In our case, our sample is homogeneous, which allows us to use the DEA method without any problems. In the case of SFA, we also need to split the simulation into two output variables and compare or choose one variable. This approach, previous experience in the literature and the availability of the necessary data allow us to carry out the analysis by both methods, which in the next part we will do and compare both approaches.

In the literature, there are already known works on the analysis of the efficiency of steel enterprises, which used both methods Wang & Feng (2011). They both gave similar results on the sample; the exponential distribution was used as a model for the SFA.

As an approach for the DEA model, the approach of the CCR, a subdivision of the CCR-I was chosen. This method will allow us to assess only the technical efficiency of steel enterprises, not including the economic one. This model also considers the effect of scale, which is especially important when we consider only a few of the largest enterprises, which have an 87% share of the steel market. At the same time, from the point of view of practical recommendations, due to the data-driven approach, we will be able to formulate more accurate recommendations, which consist in reducing certain inputs. This is a more realistic recommendation than a recommendation for the type of revenue or profit increase. Also, this method has been prevalent in many studies of the effectiveness of steel production in a literature review: Mitra Debnath & Sebastian (2014), Yayar et al. (2012), Yang et al. (2017), Nguyen & Nguyen (2020).

2.3.Plan of empirical research

The research will be carried out in several stages. First, the research gap will be described and identified. Secondly, all the required secondary data will be collected. After that, based on this data, efficiency points will be calculated for each steel company in several ways (DEA and SFA) over several years. Each steel company will be assigned a technical efficiency number, where 1 is maximum efficiency and 0 is inefficiency. After identifying stable effective companies, they will be displayed in the table.

The next part of the study will explore the reasons why these companies are the most efficient in terms of technical efficiency. First, the size of the companies by revenue will be considered and a comparison will be made. A number of plants analysis will also be carried out to determine if the this number affects the technical performance. After that, an analysis of the specialization of the companies will be carried out, whether the technical efficiency depends on the choice of the direction of product development, for example, whether the companies who focus on the production of sheet products are more technical efficiency.

The final conclusion of the work will be conclusions and managerial applications that can be applied by steel companies to analyze their performance and increase their technical efficiency.

Conclusion

In this chapter, we looked at data selection and time interval, including the specification of variables that will be selected as input and output data. The pros and cons of choosing quantitative analysis as the primary method have also been described. Then, DEA and SFA were described and proven as the methods of analysis used, including the various pros and cons of one and the other method of analysis. The specifications of each of the models were also selected based on logic and previous experience from the literature. Also, a plan was drawn up for the study to be carried out.

In the next chapter, we will conduct research based on our current understanding of sample and research methods. In the next chapter, we will provide recommendations that will help businesses optimize production.

3. FINDINGS AND MANAGERIAL RECOMMENDATIONS

This chapter analyzes by two methods and presents various interesting research findings. It will start with an analysis of the DEA, we will show the results of the influence of various parameters on the efficiency of companies, we will also show that the SFA method for our analysis will not be as effective as the DEA, and finally various recommendations for management will be presented.

3.1. Operational efficiency of Russian steel companies with DEA approach

To begin with, a descriptive analysis was carried out for the last 10 years of steel production data using the CCR method. We used data from the 6 largest steel companies of Russia and calculated the average, maximum, minimum and standard deviation of the performance score for each year. As you can see from the data, we got the minimum performance score in 2015 which is equal 0.7067. In terms of efficiency, the most efficient year was 2016, where our efficiency score was 0.9351.

We can trace the relative dynamics, which is equal to the average value of the effective ratings of each of the steel companies for each year, as we can see from the data, we saw an increase in technical efficiency from 2014 to 2016, and then a small decline began. These results show how important it is for companies in this market to monitor this metric and stick to the best results in the market. This fact can be explained by the fact that after 2016 companies began a race for digitalization and cost reduction, thereby increasing their costs in the short term, but in the long term we may increase an even greater efficiency indicator. One of the suggestion for companies can be more careful monitoring of the costs that go into the production of steel products.

Table 2. Descriptive statistics of the DEA model from 2016 to 2020

	2016	2017	2018	2019	2020	All years
Average	0,9351	0,8819	0,8683	0,8625	0,8399	0,85884
Max	1	1	1	1	1	1
Min	0,7785	0,822	0,7995	0,7657	0,7158	0,75141
St Dev	0,0834	0,0682	0,0773	0,096	0,1025	0,08982

Source: author

Table 3 Descriptive statistics of the DEA model from 2011 to 2015

	2011	2012	2013	2014	2015	All years
Average	0,8679	0,8274	0,8112	0,8194	0,8748	0,85884
Max	1	1	1	1	1	1
Min	0,761	0,711	0,7413	0,7126	**0,7067**	0,75141
St Dev	0,0798	0,0976	0,0951	0,0989	0,0994	0,08982

Source: author

Efficiency ratings with minimum values of around 0.7 indicate that steel companies in the Russian market have good performance indicators. In the next part, we will consider in detail each company using DEA analysis and give practical recommendations for each of the companies.

3.2. Finding best performers among Russian steel companies and recommendations

In this sub-chapter, we want to review the technical performance of companies and give practical advice to each company based on the DEA model and the main trends in the steel industry.

Evraz

The metallurgical company Evraz is a vertically integrated metallurgical and has two steel production facilities, one of which is the only one in southern Siberia. This company specializes in long products and is the largest supplier of railroad rails in Russia.

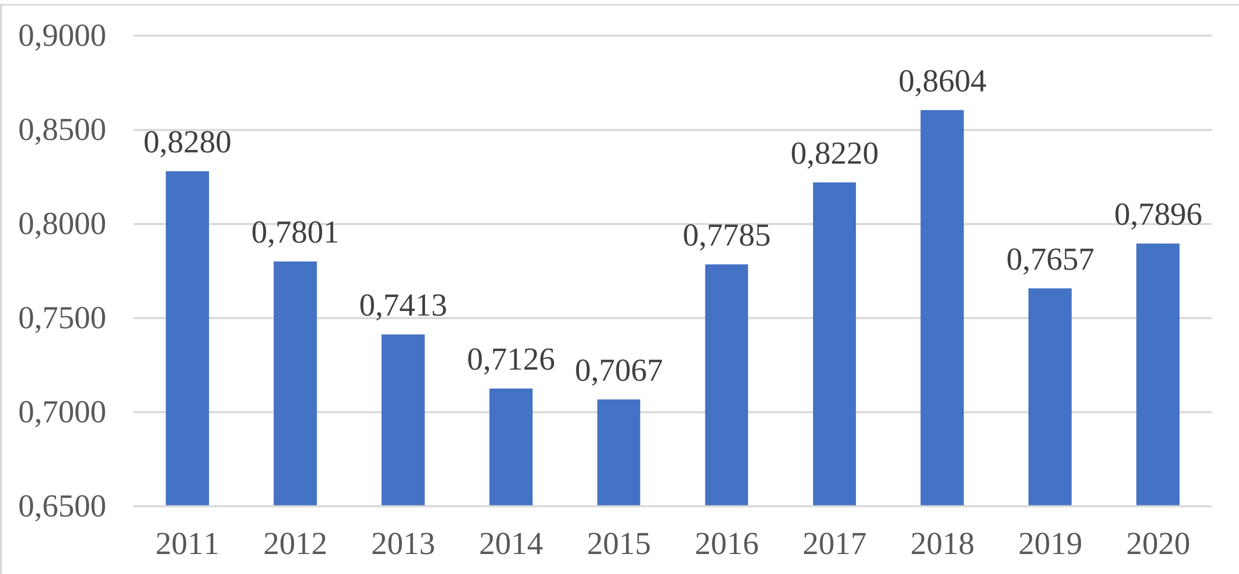

Figure 3 Technical efficiency of Evraz over 10 years

Source: author

As we can see in Figure 3, Evraz had the lowest technical efficiency in 2015, after which it made a high jump up to 2018, and then the technical efficiency indicator began to decline. This is most likely due to volatile prices for steel products that took place in 2019. he maximum result was achieved in 2018

To achieve the revenues and profits that Evraz achieved in 2020, we can see that the amount of assets could be halved to achieve the same result, and operating expenses could be reduced by 21%. The amount by which it costs to reduce assets tells us that Evraz is not using its resources optimally enough, for example, this company could be swept towards the production of more marginal rolled products in order to generate more revenue per unit of fixed assets.

Table 4. recommendations for reducing resources to achieve the same output result for Evraz

Fixed Assets		Operating Cost		COGS	
Data	Diff.(%)	Data	Diff.(%)	Data	Diff.(%)
8710	-47,353	8178	-21,038	6712	-38,325

Source: author

NLMK

NLMK Group is a vertically integrated metallurgical company and, as it claims itself, is the most efficient metallurgical company in Russia. The company specializes in the production of sheet metal and high-value-added products, such as galvanized steel. The company has three production facilities, two of which are located in the central part of Russia, and one in the Urals.

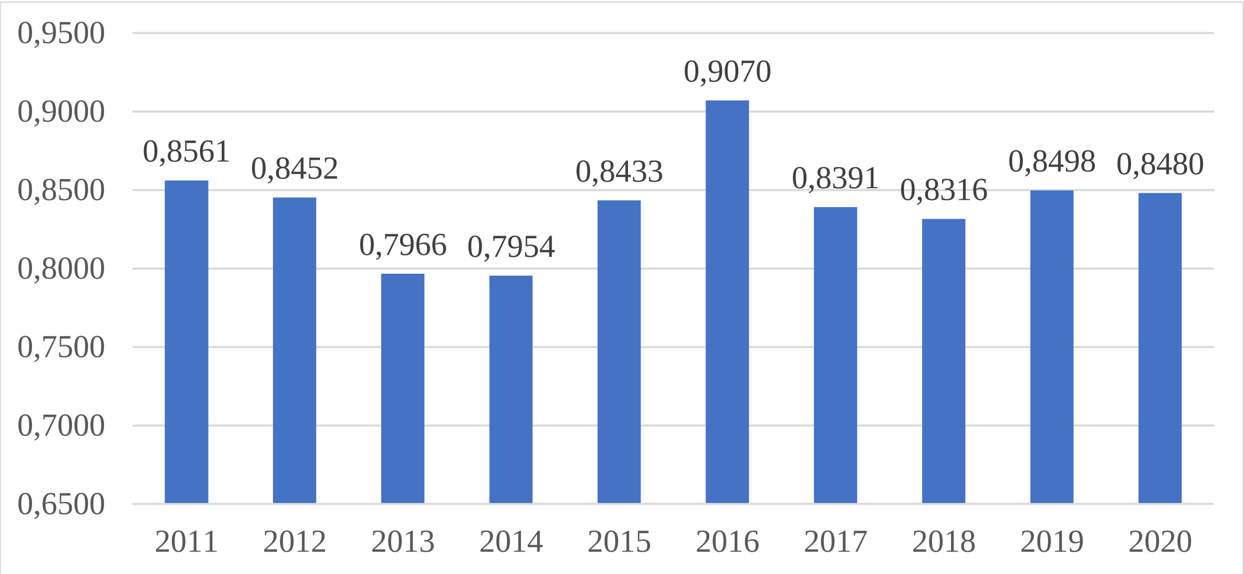

Figure 4 Technical efficiency of NLMK over 10 years

Source: author

As we can see in Figure 4, NLMK has a stable technical efficiency, which is at a stable level with small drawdowns in 2013 and 2014, as well as slight growth in 2016. This is explained by the fact that, given the price volatility for steel, which all steel companies suffer from, the least change is the prices for high value-added metal, which NLMK specializes in, which will allow this company to maintain a stable level of technical efficiency.

To achieve the desired result of technical efficiency, as we can see from Table 5, NLMK needs to focus on reducing assets mainly, since the company has several facilities, it is worth improving production capacity and increasing output at NLMK-Ural and NLMK-Kaluga, which are not working at full capacity, and the company is not so bad with operating costs, which says that the company is almost efficient in terms of production. Also, the basis of NLMK's portfolio is slabs, which are steel goods of base value, the company should move towards sheet metal with high added value.

Table 5. recommendations for reducing resources to achieve the same output result for NLMK Group

Fixed Assets		Operating Cost		COGS	
Data	Diff.(%)	Data	Diff.(%)	Data	Diff.(%)
12245	-64,506	7218	-15,205	5920	-33,723

Source: author

Severstal

PJSC "Severstal" is a vertically integrated mining and metallurgical company, which is based on value-added steel (sheet steel and galvanized steel). The company has the only production facility in Russia located in the central part of Russia, in the city of Cherpeovets.

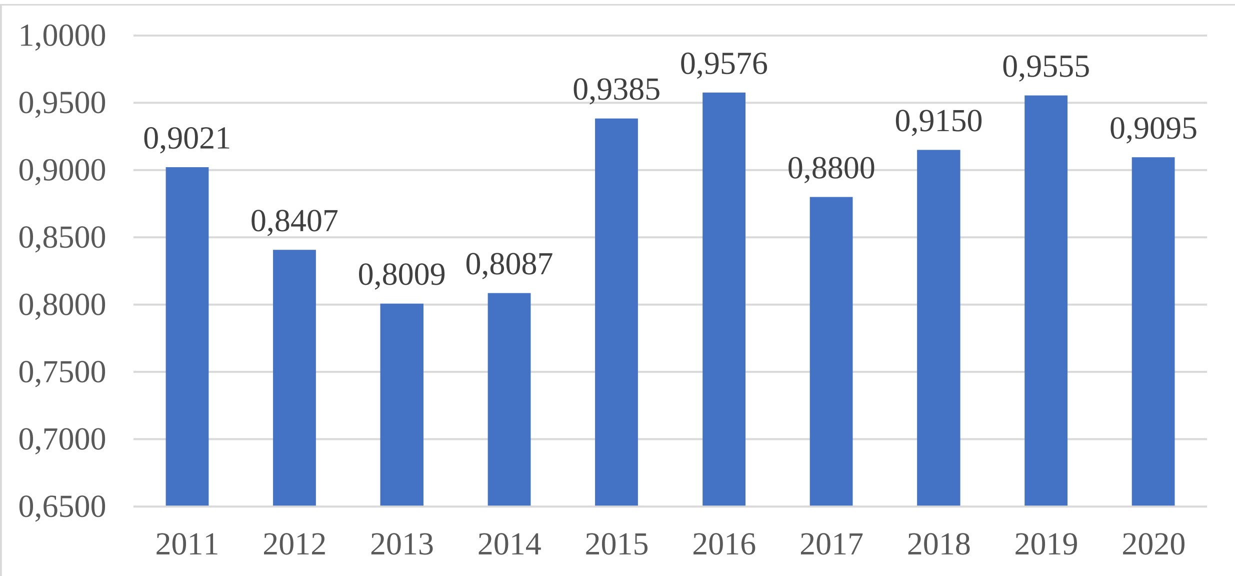

Figure 5 Technical efficiency of Severstal over 10 years

Source: author

As we can see in Figure 5, Severstal had very high efficiency rates of about 95% in 2019,2016 and 2015. The company as a whole has a high technical efficiency, for example, in 10 years the technical efficiency of the company did not fall below 0.8. After 2014, there was an overall increase in technical efficiency and after 2014 did not fall below 0.88. This is due to the product specificity of Severstal, as the company specializes in high value-added products and has undergone a transformation to sheet metal and high value-added products over these 10 years.

To achieve the desired level of technical efficiency, the company needs to look at fixed assets, as it would be possible to reduce fixed assets to achieve the same level of revenue and profit. At the same time, the rate of per-iteration is one of the best among all companies, excluding the best performer. This is due to the portfolio of products owned by the company, which allows Severstal to spend resources as efficiently as possible. The company needs to continue to improve its portfolio, as well as think about selling non-profitable assets.

Table 5. recommendations for reducing resources to achieve the same output result for Severstal

Fixed Assets		Operating Cost		COGS	
Data	Diff.(%)	Data	Diff.(%)	Data	Diff.(%)
8127	-60,259	5001	-9,054	3952	-26,223

Source: author

MMK

The Magnitogorsk Metallurgical Combine is a Russian metallurgical plant in the city of Magnitogorsk, Chelyabinsk Region, it is specialized in the production of high-value-added steel and mainly produces sheet metal. The plant has two types of furnaces, both electric and converter type.

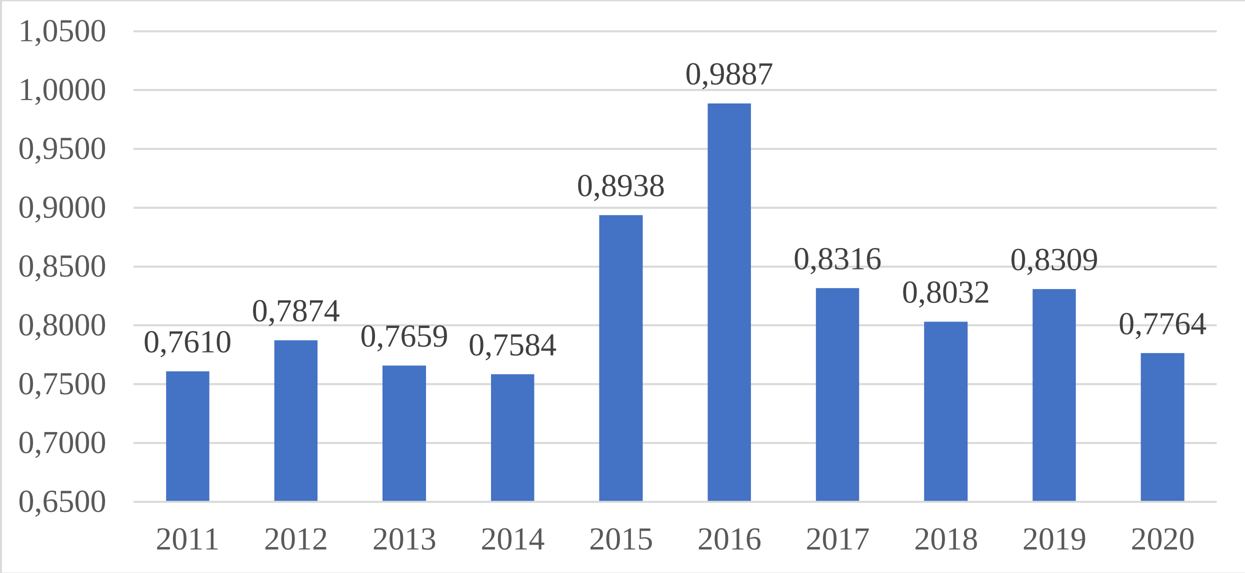

Figure 6 Technical efficiency of MMK over 10 years

Source: author

As you can see on the figure 6, MMK has rather low performance indicators with the exception of 2015 and 2016. This is due to the fact that the company produces high-value-added rolled products, but does not receive enough revenue, this is possible for several reasons, high competition in the region, due to which the market prices for steel are falling, or a low number of additional services provided to steel build a vertical sales network with additional engineering services to increase revenue per ton of steel.

As we can see from Figure 6, MMK could generate the same amount of revenue at the lowest cost. MMK has the worst result among all in terms of cost of sales, which can tell us that it is too expensive for MMK to sell its products, which signals problems in the production of products. It is necessary for MMK to optimize the cost of creating value, consider in more detail the value of the chain of creating rolled products.

Table 6. recommendations for reducing resources to achieve the same output result for MMK

Fixed Assets		Operating Cost		COGS	
Data	Diff.(%)	Data	Diff.(%)	Data	Diff.(%)
10056	-70,103	5453	-22,36	4711	-42,389

Metalloinvest

Metalloinvest - one of the largest mining and metallurgical holdings in Russia, has several factories in the southern part of Russia, which specialize mainly in long-range rolled products and steel billets.

In our research, Metaloinvest is the best performer in each of the periods, therefore, it has a stable performance soon in each of the periods. The company achieves these results with huge volumes of black ore supplied to the market, which can be mined at low costs and low fixed costs. Nevertheless, if the company wants to continue to be among the leaders in terms of technical efficiency of production, then it should pay attention to investments in products of Industry 4.0, as well as optimization of the product portfolio towards products of high added value.

Mechel

Mechel Group is a global mining and metallurgical company with production in the city of Chelyabinsk, which specializes in long products and steel billets. The company has both an electric furnace and a converter type furnace.

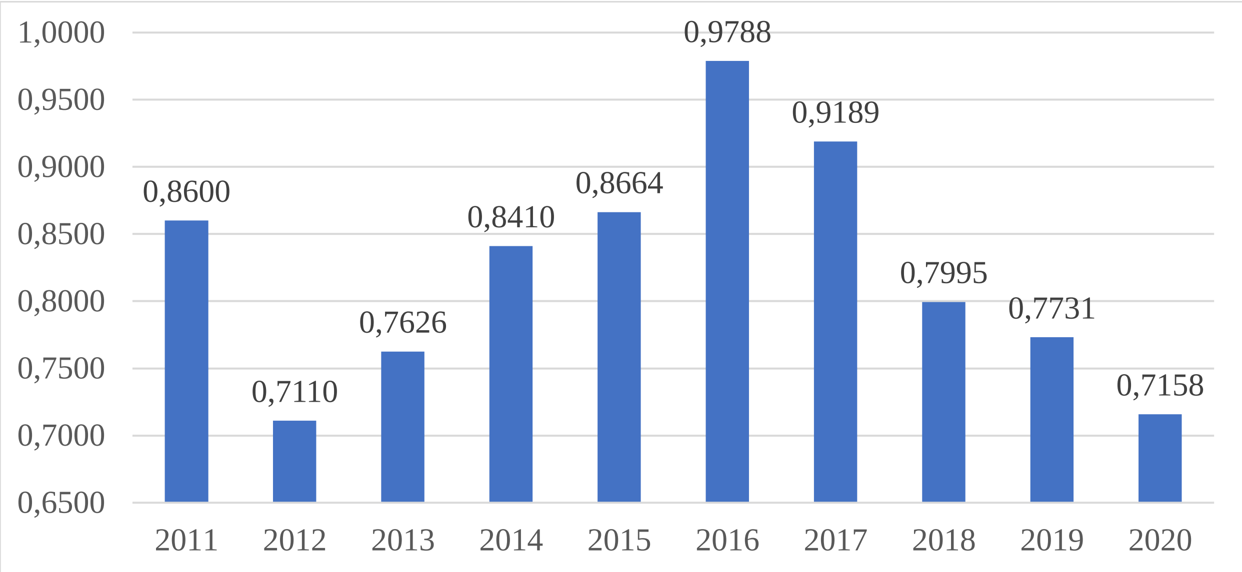

Figure 7 Technical efficiency of Mechel over 10 years

Source: author

As you can see in Figure 7, the Mechel company has a distribution of efficiency similar to the normal distribution, after 2016 the technical efficiency of the company has been declining from year to year. This is due to the product portfolio of this company and the utilization of production facilities. The company specializes mainly in long products, which have low added value, because of this, such a variable level of technical efficiency.

From the table of recommendations for reducing resources, we can see that Mechel has the lowest operating cost efficiency, this is related to the product basket of this company, and it is recommended to go to the side of product differentiation and increase products in the portfolio with high added value. The company also has a low utilization of capacities, which increases the load of fixed costs on revenue, since production does not affect all capacities by 100%, most of the fixed costs are borne by the unit of steel produced.

Table 7. recommendations for reducing resources to achieve the same output result for Mechel

Fixed Assets		Operating Cost		COGS	
Data	Diff.(%)	Data	Diff.(%)	Data	Diff.(%)
3349	-48,384	3401	-28,424	2363	-33,96

3.3. Impact of product portfolio, company size and number of plants on the efficiency of steel companies.

In this part we will look at our steel companies, which will be grouped by number of plants, product portfolio and company size. The exact breakdown of companies into groups can be found in Appendix 3.

In order to determine whether the size of the company affects efficiency, we divided the steel companies into groups: large, medium, and small companies. Big companies start at $ 9 billion in annual revenues, medium-sized companies start at $ 6 billion, and small companies all the rest.

On average, large companies showed the lowest results in terms of efficiency, this may be due to the fact that large companies find it difficult to manage large resources, for example, large companies in our sample have 2 or 3 production facilities and from the point of view of management it is difficult to control all factories. One way to improve the problem is through new management and control systems.

Also, we can see that small companies also have less performance sooner than medium ones, this may be due to the fact that there are economies of scale in the average business. To achieve the same performance indicators, small companies should expand their business or merge others to increase the amount of steel produced and economies of scale.

Table 8 Average efficiency scores for 10 years of steel companies of different sizes

	Large companies	**Medium companies**	**Small companies**
Average score	0,8099	0,9035	0,8227

Source: author

Figure 8 shows the dynamics of the effectiveness of different groups over 10 years. as we can see, the efficiency of large companies is consistently lower in each of the years than that of medium-sized companies.

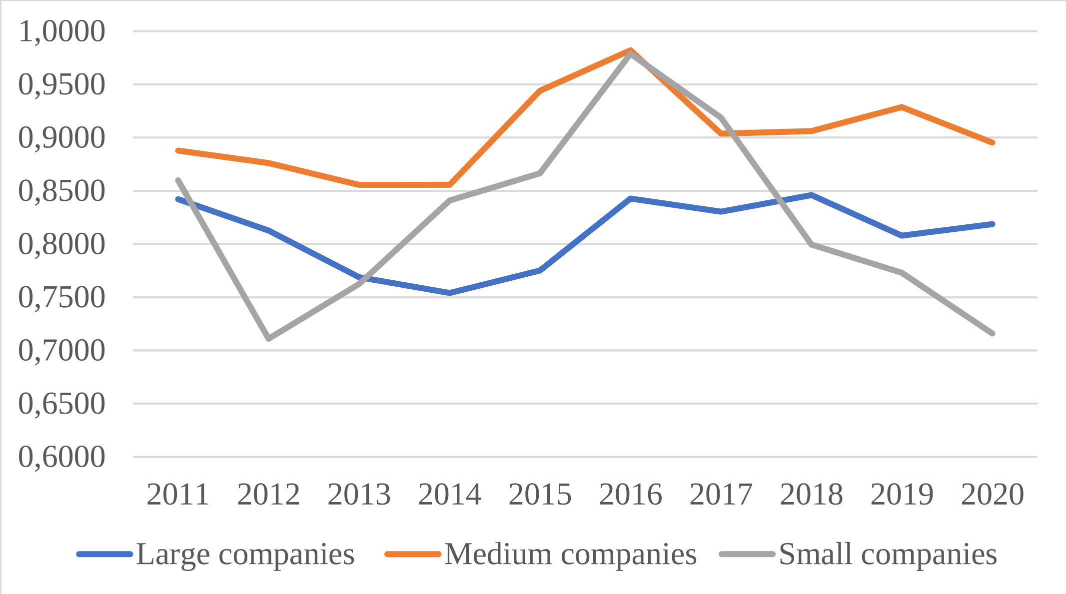

Figure 8 Efficiency scores of steel companies of different sizes

Source: author

As well as size, the number of plants can also play a role in efficiency. In other countries, it is common practice to build small factories that are aimed at meeting internal local demand. So in our market there are companies that have factories that do not produce enough metal and are focused on the domestic market.

As can be seen from Figure 9, most of the periods were efficient production with an average number of factories. This fact can be explained by the fact that steel companies that have several plants at their disposal can optimally allocate resources, so from the point of view of geography, Evraz can dominate the Siberian market, since its plant is closest to the facilities of Eastern and Central Siberia and Evraz will be able to provide high speed of order delivery.

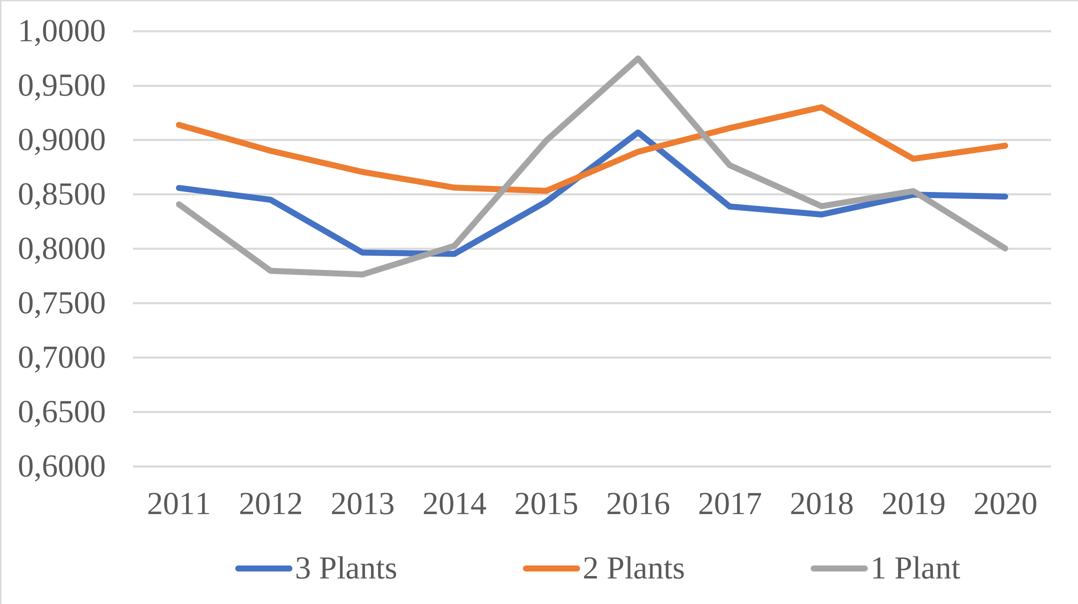

Figure 9 Efficiency scores of steel companies with different number of plants

Source: author

As we said earlier, specializing in different product portfolios can greatly affect the efficiency of a company, since products with high added value bring more output than input data. Therefore, it is worth to compare companies that specialize in value-added products and companies that specialize in billets and long products.

As you can see in Figure 10, in the first 5 years of our period, companies that specialized in low-value products were more efficient, but that all changed in 2015 when companies began to diversify their product portfolios. In the last 5 years of our sample, you can see that companies that specialize in high-added value products have become more efficient. Despite the fact that our best performer, which specializes in low-value-added products, has recently been established by high-value-added companies, this tells us that in terms of efficiency, companies that produce sheet and galvanized steel will be more efficient in the future. In order for companies to maintain their advantage in efficiency, they should diversify their portfolio towards products with high added value.

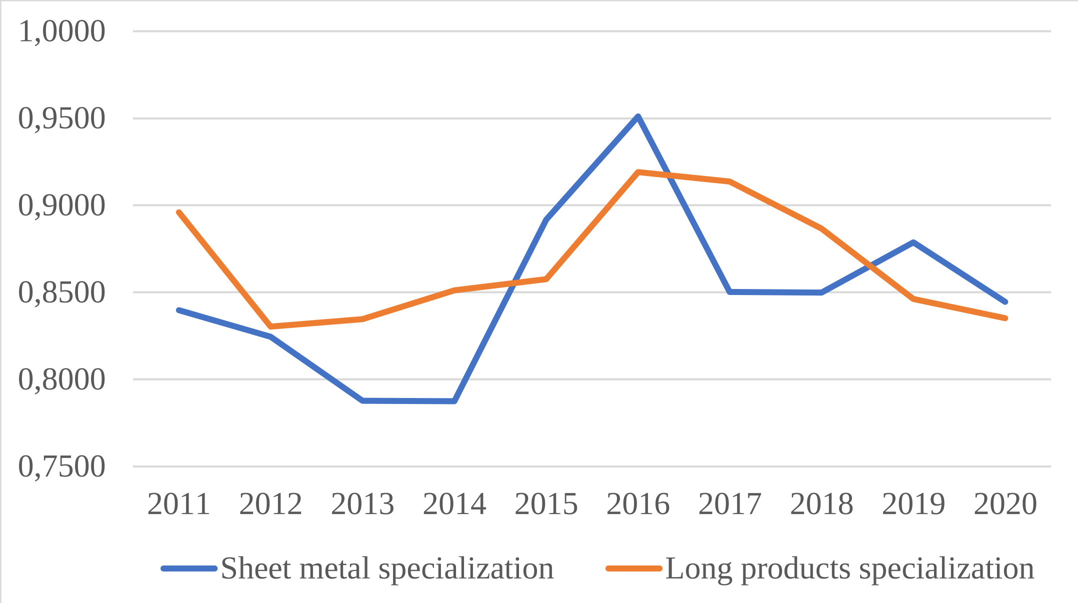

Figure 10 Efficiency scores of steel companies with different specialization

Source: author

3.4. Operational efficiency of Russian steel companies with SDA approach.

In this section we will show that the SFA method for our analysis will not be as effective as DEA. Firstly, the SFA can take into account only one output parameter, while our data contains two output indicators, and we cannot use two at once in this method.

Also, we do not need to look for and look for a production function. Thirdly, this method does not show, and the result does not give recommendations on what needs to be done to improve efficiency.

Moreover, in our review of the literature, we looked at works in which both methods were present and the results were not very different in determining effective units (Resti, 1997; Wang & Feng, 2011)

According to the stochastic frontier production function proposed by other researchers we set it to: $Ln(Net\ Sales) = \alpha_0 + \ln(Fixed\ Assets) + \ln(Operating\ Cost) + ln(COGS) + v_t + u_t$, where v_t is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. The error component is u_t assumed to be distributed independently of v_t, and to satisfy u_tt≤0.

We conducted an introductory analysis and obtained the results of the most effective companies for the entire foreseeable period. You can see the performance estimates in the appendix 4. As you can see from the table 9, Our best performer from the previous analysis was also included in the list 3 times, but what is more interesting in this list also companies were included in the list 3 times, such as Severstal and NLMK. Our best perfomer from the previous analysis was also included in the list 3 times, but what is more interesting in this list also companies were included in the list 3 times, such as Severstal and NLMK. This tells us that companies that specialize in high value-added products are more efficient in relation to other enterprises in the steel industry.

Table 9 The number of times the company has become effective in the foreseeable period

Company	Target	Getting into effective companies
Evraz	long products	1
NLMK	sheet metal	3
Seversteel	sheet metal	3
MMK	sheet metal	0
Metalloinvest	long products	3
Mechel	long products	0

Source: author

Conclusions

This chapter summarizes the basic conclusions we have drawn from the data and is systematized in a logical and coherent manner. It all starts with descriptive analytics and provides data for the entire study period and average and minimum estimates of the effectiveness of all companies. Then a detailed analysis of the effectiveness of each of the companies is carried out over a 10-year interval, and then both recommendations for the DEA model and precise recommendations based on the performance data from the model and the current situation of the company are provided. Then the sample is grouped according to different factors and a study is carried out whether various factors affect the efficiency of companies. Moreover, SFA analysis was also carried out, which showed 3 top performers: Seversteel, NLMK and Metalloinvest.

4. DISCUSSION OF THE FINDINGS

4.1. Research implications

This research complements the existing benchmarking research section of steel companies. This study analyzes the concept of efficiency and provides a brief overview and trends of the Russian steel market.

This study seeks to bridge the gap that was found in the literature review and conduct the first study using modern methods of analyzing the efficiency of steel enterprises in Russia.

This research uses DEA and SFA methods for the first time on the Russian steel market to compare efficiency. As part of the study, techniques were carried out to normalize one of the output data, as well as to combine the available information on production into a single model.

Thus, this study provides an opportunity for future studies to take advantage of the current findings and obtained metrics to conduct the study in the next years. Also, this study can half-narrow the basis for the selection of inputs and outputs for the following model of the further research.

This paper not only considers performance evaluations and finds a best performer in the steel market, which can help company managers and executives understand where the company was and is now in terms of performance.

This study also invites executives and managers of steel companies to familiarize themselves with proposed solutions to problems based on the obtained performance metrics and benchmarking performance over the past 10 years.

Also, the given method of assessing the effectiveness in this research can be taken as a basis for further research by company managers. Moreover, this study will be useful to government agencies responsible for the development of the steel industry in Russia to formulate recommendations for steel firms.

4.2. Research limitations

Despite the choice of modern methods of analysis and the most suitable for this study, this paper contains some limitations.

Firstly, in this study we choose 5 variables as input and output data, which is too many for these 6 companies in Russia. This limitation cannot be bypassed, since it so happened on the Russian market that the main market is controlled by 6 steel conglomerates.

Secondly, the conclusions and metrics from the model do not allow 100% to draw the correct conclusion and recommendation for changing the situation for the better, the proposed improvements are based on the assessment of the current market position and trends in aggregate with the data obtained, so such conclusions cannot be generalized.

Future researchers can increase the number of observations in the next study, for example, by adding to the study not only Russian companies, but also companies from the CIS for more accurate analytics.

Despite the limitations, the conclusions that this study offers are objective and correct, therefore, can be used by various stakeholders for application in business or future research.

LIST OF REFERENCES

A. Charnes, W. W. Cooper and E. Rhodes (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 1978, vol. 2, issue 6, 429-444. doi:10.1016/0377-2217(78)90138-8

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). SOME MODELS FOR ESTIMATING TECHNICAL AND SCALE INEFFICIENCIES IN DATA ENVELOPMENT ANALYSIS. Management Science, 30(9), 1078-1092. doi:10.1287/mnsc.30.9.1078

Battese, G. E., & Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empirical Economics, 20(2), 325–332. https://doi.org/10.1007/BF01205442

Brambilla, C., & Lavista, F. (2021). Privatizations and efficiency. evidences from the italian iron and steel industry, 1979-2016. Industrial and Corporate Change, 29(3), 757-778. doi:10.1093/ICC/DTZ060

Cooper, W. W., Park, K. S., & Pastor, J. T. (1999). RAM: A range adjusted measure of inefficiency for use with additive models, and relations to other models and measures in DEA. Journal of Productivity Analysis, 11(1), 5-42. doi:10.1023/A:1007701304281

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of industry 4.0 technologies for industrial performance. International Journal of Production Economics, 204, 383-394. doi:10.1016/j.ijpe.2018.08.019

El-Kassar, A. -., & Singh, S. K. (2019). Green innovation and organizational performance: The influence of big data and the moderating role of management commitment and HR practices. Technological Forecasting and Social Change, 144, 483-498. doi:10.1016/j.techfore.2017.12.016

Farrell, M. (1957). “The Measurement of Productive Efficiency.” Journal of the Royal Statistical Society (Series A: General) 120, 253–281.

Feng, C., Huang, J. -., Wang, M., & Song, Y. (2018). Energy efficiency in china's iron and steel industry: Evidence and policy implications. Journal of Cleaner Production, 177, 837-845. doi:10.1016/j.jclepro.2017.12.231

Filippini, M., Geissmann, T., Karplus, V. J., & Zhang, D. (2020). The productivity impacts of energy efficiency programs in developing countries: Evidence from iron and steel firms in china. China Economic Review, 59 doi:10.1016/j.chieco.2019.101364

Garanina, T., & Petrova, O. (2015). Liquidity, cash conversion cycle and financial performance: Case of russian companies. Investment Management and Financial Innovations, 12(1), 90-100.

Gruver, G. W., & Yu, S. (1985). Variable factors and efficiency in the US steel industry: A production frontier analysis. Applied Economics, 17(1), 117-134. doi:10.1080/00036848500000010

Hosios, A. J. (1990). On the efficiency of matching and related models of search and unemployment. Review of Economic Studies, 57(2), 279-298. doi:10.2307/2297382

Karakaya, E., Nuur, C., & Assbring, L. (2018). Potential transitions in the iron and steel industry in sweden: Towards a hydrogen-based future? Journal of Cleaner Production, 195, 651-663. doi:10.1016/j.jclepro.2018.05.142

Kim, J. W., Lee, J. Y., Kim, J. Y., & Lee, H. K. (2006). Sources of productive efficiency: International comparison of iron and steel firms. Resources Policy, 31(4), 239-246. doi:10.1016/j.resourpol.2007.03.003

Kolosova, E. S. (2011). Approaches to formation of effective banking system. Audit and Financial analysis, 4(2), 0-5. Retrieved from http://www.auditfin.com/fin/2011/4/2011_IV_10_10.pdf

Lee, K., & Ki, J. -. (2017). Rise of latecomers and catch-up cycles in the world steel industry. Research Policy, 46(2), 365-375. doi:10.1016/j.respol.2016.09.010

Li, H. -., Zhu, X. -., Chen, J. -., & Jiang, F. -. (2019). Environmental regulations, environmental governance efficiency and the green transformation of china's iron and steel enterprises. Ecological Economics, 165 doi:10.1016/j.ecolecon.2019.106397

M. J. Farrel, M. Fieldhouse (1962), Estimating efficient production functions under increasing returns to scale, J. Roy. Statist. Soc. Set. A, II 252-267.

Ma, J., Evans, D. G., Fuller, R. J., & Stewart, D. F. (2002). Technical efficiency and productivity change of china's iron and steel industry. International Journal of Production Economics, 76(3), 293-312. doi:10.1016/S0925-5273(01)00195-5

McAllister, P. H., & McManus, D. (1993). Resolving the scale efficiency puzzle in banking. Journal of Banking and Finance, 17(2-3), 389-405. doi:10.1016/0378-4266(93)90039-G

Mitra Debnath, R., & Sebastian, V. J. (2014). Efficiency in the indian iron and steel industry – an application of data envelopment analysis. Journal of Advances in Management Research, 11(1), 4-19. doi:10.1108/JAMR-01-2013-0005

Movshuk, O. (2004). Restructing, productivity and technical efficiency in china's iron and steel industry, 1988-2000. Journal of Asian Economics, 15(1), 135-151. doi:10.1016/j.asieco.2003.12.005

Müller, J. M., Buliga, O., & Voigt, K. -. (2018). Fortune favors the prepared: How SMEs approach business model innovations in industry 4.0. Technological Forecasting and Social Change, 132, 2-17. doi:10.1016/j.techfore.2017.12.019

Nguyen, N. M., & Tran, K. T. (2021). Factors influencing business efficiency of steel firms: Evidence from vietnam. Journal of Asian Finance, Economics and Business, 8(1), 295-304. doi:10.13106/jafeb.2021.vol8.no1.295

Nguyen, P., & Nguyen, N. T. (2020). Using optimization algorithms of DEA and grey system theory in strategic partner selection: An empirical study in vietnam steel industry. Cogent Business and Management, 7(1) doi:10.1080/23311975.2020.1832810

Peter F. Drucker (2006). The Effective Executive: The Definitive Guide to Getting the Right Things Done. New York: Collins.

Resti, A. (1997). Evaluating the Cost-efficiency of the Italian Banking System: What Can Be Learned from the Joint Application of Parametric and Non-parametric Techniques. Journal of Banking and Finance, 21(2), 221–250.

Schickele, R. (1941). Effect of tenure systems on agricultural efficiency. American Journal of Agricultural Economics, 23(1), 185-207. doi:10.2307/1231850

Trüby, J. (2013). Strategic behaviour in international metallurgical coal markets. Energy Economics, 36, 147-157. doi:10.1016/j.eneco.2012.12.006

Wang, Z., & Feng, M. (2011). Efficiency analyzing of enterprises of different ownership in china's iron and steel industry. Paper presented at the 2011 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce, AIMSEC 2011 - Proceedings, 328-331. doi:10.1109/AIMSEC.2011.6010430 Retrieved from www.scopus.com

Wanghui, L., & Bing, H. (2009). A decomposition of total factor productivity growth in China¡s steel industry: A stochastic frontier approach. Paper presented at the 2009 International Conference on Business Intelligence and Financial Engineering, BIFE 2009, 849-852. doi:10.1109/BIFE.2009.203 Retrieved from www.scopus.com

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. International Journal of Production Research, 56(8), 2941-2962. doi:10.1080/00207543.2018.1444806

Yang, W., Shi, J., Qiao, H., Shao, Y., & Wang, S. (2017). Regional technical efficiency of chinese iron and steel industry based on bootstrap network data envelopment analysis. Socio-Economic Planning Sciences, 57, 14-24. doi:10.1016/j.seps.2016.07.003

Yayar, R., Karaca, S. S., & Erol, Y. (2012). Data envelopment analysis approach for the measurement of ISO500 firms' efficiencies: Iron-steel basic metal industry. European Journal of Economics, Finance and Administrative Sciences, (47), 19-29.

Zellner, A., & Revankar, N. S. (1969). Generalized production functions. Review of Economic Studies, 36(2), 241-250. doi:10.2307/2296840

Zhang, Y. -., Shi, W., & Jiang, L. (2020). Does china's carbon emissions trading policy improve the technology innovation of relevant enterprises? Business Strategy and the Environment, 29(3), 872-885. doi:10.1002/bse.2404

APPENDICES

Appendix 1 literature review summary: papers, methods, specifications

Author	Method	Approach to data	Inputs	Outputs
Efficiency estimation of steel componies				
Ma et al. (2002)	DEA and MALM	Operational	Energy Other resources (Number of workers)	Iron Steel
Movshuk, O. (2004)	Stochastic frontier approach	Financial	Fixed assets Number of staff and workers	Gross output
Kim et al. (2006)	Stochastic frontier approach	Economical	Total number of employees Crude steel production capacity of equipment (millions of tons) Other material inputs employed (thousands of US dollars) Private ownership	Crude steel production (millions of tons)
Wanghui & Bing(2009)	Stochastic frontier approach	Economical	Number of productive workers Net fixed assets	Added value of steel industry
Wang & Feng (2011)	Data Envelopment Analysis and SFA	Financial and Economical	Average balance of fixed assets Annual average of staff number	Annual industrial value
Yayar et al. (2012)	Data Envelopment Analysis	Financial	Net Assets Equity Number of Employees	Net Sales Export Pre-Tax Profit
Mitra Debnath & Sebastian (2014)	Data Envelopment Analysis	Financial	Gross fixed assets Total energy cost Total number of employees Currents assets	Income Sales PBIT PAT

Appendix 1 (continuation 1/2)

Yang et al. (2017)	DEA and smoothed bootstrap network DEA	Economical	Investment in fixed assets Number of employed persons in steel industry	Crude steel Finished steel
Feng et al. (2018)	Data Envelopment Analysis	Economical	Labor input Capital stock Energy input	Economic output CO2 emissions
Li et al. (2019)	DEA and MALM	Economical	Capital input Labour input Waste discharge	Expected output Undesirable outputs
Filippini et al. (2020)	Törnqvist index and Data Envelopment Analysis	Financial and Economical	Employees Total assets	Gross output
Nguyen & Nguyen (2020)	Data Envelopment Analysis and Grey system theory	Financial	Fixed assets Cost of goods sold Capital Operating Costs	Net sales Net profit

Appendix 1 (continuation 2/2)

Nguyen & Tran (2021)	Regression model	Financial and Economical	The length variable of agency i, measured through the logarithm of the asset fee of the agency i. Variable increase price of an agency is same to the increase price of overall property of the agency i. Variable capital shape of the business, measured through the debt to fairness ratio of the corporation i. Variable shape of exact property of the agency, same to the ratio of common long-time period property to overall property of the agency i.	ROA Profit after tax

Appendix 2 Basic parameters of steel companies in Russia

DMU's	Company	Target	Size	Nmber of plants
DMU1	Evraz	long products	Big	2
DMU2	NLMK	sheet metal	Big	3
DMU3	Seversteel	sheet metal	Medium	1
DMU4	MMK	sheet metal	Medium	1
DMU5	Metalloinvest	long products	Medium	2
DMU6	Mechel	long products	Small	1

Appendix 3 Financial data of Russian steel companies

		Input Variables			Output Variables	
2020	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	8710	8178	6712	9754	848
NLMK	DMU2	12245	7218	5920	9245	1580
Seversteel	DMU3	8127	5001	3952	6870	1016
MMK	DMU4	10056	5453	4711	6395	603
Metalloinvest	DMU5	3013	4243	2720	6409	1726
Mechel	DMU6	3349	3401	2363	3677	11

		Input Variables			Output Variables	
2019	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	10311	10744	8273	11905	902
NLMK	DMU2	13209	8582	7303	10554	1794
Seversteel	DMU3	8297	5899	4908	8157	2232
MMK	DMU4	11293	6292	5534	7566	1095
Metalloinvest	DMU5	3354	4810	3195	6960	2219
Mechel	DMU6	5931	4099	2905	4586	190

		Input Variables			Output Variables	
2018	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	8877	9308	8011	12836	3201
NLMK	DMU2	10857	9038	7680	12046	2729
Seversteel	DMU3	6586	5855	4918	8580	2519
MMK	DMU4	9697	6381	5559	8214	1775
Metalloinvest	DMU5	2697	4484	3268	7187	2109
Mechel	DMU6	5051	4185	2831	4978	258

		Input Variables			Output Variables	
2017	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	10115	8841	7485	10827	1155
NLMK	DMU2	12180	8051	6798	10065	1823
Seversteel	DMU3	7210	5986	4735	7848	1764
MMK	DMU4	10632	6091	5296	7546	1495
Metalloinvest	DMU5	3140	4182	3069	6231	1771
Mechel	DMU6	5980	4143	2751	5132	270

		Input Variables			Output Variables	
2016	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	9426	7252	5521	7713	-92
NLMK	DMU2	11151	6162	5074	7636	1172
Seversteel	DMU3	6188	4522	3573	5916	1717
MMK	DMU4	9691	4168	3840	5630	1342
Metalloinvest	DMU5	2815	3119	2211	4261	1427
Mechel	DMU6	5487	3483	2186	4123	211

		Input Variables			Output Variables	
2015	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	8202	8969	6583	8767	-707
NLMK	DMU2	10226	8912	7458	10396	1770
Seversteel	DMU3	4957	4927	3787	6396	723
MMK	DMU4	8098	4723	4078	5839	613
Metalloinvest	DMU5	2299	3176	2275	4393	272
Mechel	DMU6	4674	3746	2474	4139	-1752

		Input Variables			Output Variables	
2014	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	10435	13163	9734	13061	-1084
NLMK	DMU2	10406	8912	7458	10396	1770
Seversteel	DMU3	6025	7096	5448	8296	-814
MMK	DMU4	9859	7149	6238	7952	-54
Metalloinvest	DMU5	2812	4341	3381	6367	64
Mechel	DMU6	6317	6279	4045	6406	-3070

		Input Variables			Output Variables	
2013	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	15654	14572	11501	14411	-637
NLMK	DMU2	16784	10266	8790	10909	483
Seversteel	DMU3	13530	12459	10339	13312	156
MMK	DMU4	15536	8016	6993	8190	-2735
Metalloinvest	DMU5	4577	5490	3913	7324	1395
Mechel	DMU6	12944	9182	6009	8576	-1511

		Input Variables			Output Variables	
2012	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	14131	14468	11803	14726	-191
NLMK	DMU2	18498	11024	9262	12157	915
Seversteel	DMU3	13314	12858	10785	14104	1037
MMK	DMU4	16275	9079	7915	9328	-63
Metalloinvest	DMU5	4893	6280	4147	8195	1699
Mechel	DMU6	9943	12173	8024	11275	-1377

		Input Variables			Output Variables	
2011	DMU's	Fixed Assets	Operating Cost	COGS	Net Sales	Net Profits
Evraz	DMU1	12820	14549	12480	16400	877
NLMK	DMU2	16297	10063	8369	11729	1682
Seversteel	DMU3	11601	12875	10903	15812	2429
MMK	DMU4	15204	8982	7788	9306	-141
Metalloinvest	DMU5	2961	6698	4485	9119	2024
Mechel	DMU6	8931	10715	8221	12546	1163

Appendix 4 Evaluating the effectiveness of companies using the SFA method

Company	Year	DMU's	Efficiency Score
Metalloinvest	2020	DMU5	0,9831544
NLMK	2020	DMU2	0,9817432
Seversteel	2020	DMU3	0,981243
NLMK	2018	DMU2	0,9810752
Metalloinvest	2019	DMU5	0,980178
Metalloinvest	2012	DMU5	0,9799759
NLMK	2011	DMU2	0,9795485
Evraz	2018	DMU1	0,9793119
Seversteel	2019	DMU3	0,979256
Seversteel	2018	DMU3	0,9789573